APPLICATION

OF

Murray Mahoney

FOR

UNITED STATES LETTERS PATENT

ON

ENHANCED GOLF CLUB PERFORMANCE VIA FRICTION STIR PROCESSING

Docket No. 02RSC064

Assigned to:

Innovative Technology Licensing, LL

BACKGROUND OF THE INVENTION

Field of the Invention

This invention is concerned with fabrication of golf clubs, and in particular with surface treatment of metallic golf club heads to improve performance.

Description of the Related Art

Golf club irons are generally designed to propel a golf ball through a trajectory for which the increase in the ball height (i.e., loft) for a given distance traveled is maximized. In this case, the ball impacts the ground at a relatively large angle so that it tends to roll less and remain close to the point of ground impact, which enables the golfer to exercise better control over the final location of the ball. For a high-quality golf club, properly swung, the ball should go "straight", i.e., its trajectory should define an arc lying in a vertical plane. This requires that horizontal spin be minimized so that the ball does not substantially hook to the left or slice to the right of the "straight" trajectory. On the other hand, the ability to impart backwards spin (in the vertical direction) is desirable to enable the golfer to minimize ball rolling or to cause the ball to roll backwards for enhanced control.

The golf club "face", which is the planar surface on the club head that strikes the ball, is angled to differing degrees to provide different ratios of loft to distance traveled. The club face angle (during ball impact) with respect to the vertical covers a large range for irons and tend to be larger for shorter propelled distances. The faces of irons typically have horizontal grooves whose outer edges tend to "grip" the ball during impact so that more backward spin can be imparted to the ball. These grooves also facilitate removal of water, which would change the frictional characteristics of the club face.

Other factors being constant, the loft to distance ratio is determined primarily by the club face angle and the "launch velocity" at which the ball leaves the golf club face. A higher launch velocity enables a given distance to be covered using a club with a greater face angle, which provides higher loft. Conversely, for the same launch angle, a greater distance can be achieved with an increased launch velocity. One way to increase the launch velocity is to increase the hardness of the material comprising the club face so that the kinetic energy lost due to inelasticity is minimized. Because of the irregular shapes involved, however, golf club heads are

typically fabricated by investment casting, which yields material having a relatively large-grain structure and low hardness.

Inserts of harder material may be attached to the golf club face but this does not yield optimum results. In particular, much of the benefit derived from the harder material may be offset by losses associated with energy transfer across the interface between the insert and the club head. The precision machining and secure attachment needed to minimize such losses significantly increase manufacturing costs. Inserts must also be relatively thick to withstand ball impact without deforming. Increased thickness reduces the flexibility for balancing the club's weight distribution. Such loss of flexibility is significant since peripheral weighting (around the club face) is often used to minimize the tendency of the club to twist and impart horizontal spin to the ball during impact. Horizontal spin causes the ball to deviate from a straight trajectory. A properly weighted club has a large "sweet spot" on the face for hitting the ball in a straight trajectory.

One possibility for fabricating a golf club with increased face hardness is to forge the golf club head from a fine-grained workpiece. Reduced grain size can be achieved in a metal by introducing extensive deformation. A number of conventional metal working operations are available for this purpose, such as rolling, forging, swaging and extrusion. However, such metal working operations change the grain size throughout the material so that important bulk properties, such as strength, ductility and impact resistance, are also changed. The reduced impact resistance for a golf club forged from fine-grained bulk metal would significantly limit the club durability and useful life. Further, achieving a significant grain size reduction by any of these metal working practices is not practical or economical. Note that some grain refinement occurs in the surface region of the workpiece during forging but the degree of grain refinement in this case is small. Also, during forging of golf club irons, the location of the deformed metal is predominantly within the cavity back and not at the club face. Thus, any grain refinement achieved by forging during club fabrication would have substantially no influence on grain size on the club face so that hardness and golf club performance would not be significantly improved.

Friction stir processing (FSP) involves passing a rotating FSP tool through a metallic material to locally create a fine-grain microstructure providing improved mechanical properties [F. D. Nicholas, Advanced Materials Processes 6/99, 69 (1999)]. The FSP operation is typically performed at room temperature but the friction and metal deformation involved raises the local

temperature to just below the solidus temperature so that the friction stir processed material is fully-recrystallized but does not undergo melting. Friction stir processing introduces levels of deformation considerably greater than can be achieved by conventional metal working methods, which provides exceptionally fine grain structure and greatly enhanced hardness. In addition, a thin surface layer can be friction stir processed to improve hardness without significantly affecting the mechanical properties of the bulk metal. Friction stir processing has been demonstrated for a variety of metals and their alloys, including aluminum, titanium, bronze, and steel. The FSP approach has been used to locally improve the mechanical properties in high-stress areas of cast metal parts but has not previously been applied to increasing the hardness of golf club surfaces.

SUMMARY OF THE INVENTION

This invention provides an improved golf club and a method for improving the performance of a golf club via friction stir processing (FSP) to enhance the hardness of at least a portion of the golf club face. Enhanced face hardness tends to increase the momentum transfer efficiency between the club and the ball so as to provide increased loft, increased distance, and better control over the final location of the ball. Friction stir processing also tends to remove voids and defects in the metal that might otherwise decrease momentum transfer efficiency. The friction stir processed face is also more resistant to wear, which tends to improve golfing consistency and extend the lifetime of the club. Another embodiment of the invention is a practice club that provides performance feedback to the golfer in terms of a more solid feel when the ball is struck within a friction stir processed sweet spot.

Friction stir processing, according to the present invention, may be performed after the golf club head is formed by casting or forging, for example, or may be performed on a workpiece subsequently formed into a club head, by forging, for example. The FSP depth is typically sufficiently small such that the forgability, mechanical properties, and impact resistance of the underlying bulk metal are substantially unaffected. This provides enhanced flexibility with respect to golf club fabrication and peripheral weighting, especially for forged clubs. It is generally necessary to re-surface the friction stir processed area, preferably by milling. As part of the re-surfacing operation, desirable features (grooves, for example) may be machined in the club face. The FSP treatment is inexpensive to apply, enabling high quality golf clubs to be

fabricated at reduced costs.

Further features and advantages of the invention will be apparent to those skilled in the art from the following detailed description, taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an optical micrograph of a cross-section of a friction stir processed golf club face showing the fine-grained microstructure produced in the surface region by the FSP treatment.

Figure 2 shows the hardness for friction stir processed steel as a function of distance into the material from the surface.

DETAILED DESCRIPTION OF THE INVENTION

Technical terms used in this document are generally known to those skilled in the art. Forming involves deforming a metal workpiece into a desired shape, usually by applying force or pressure to cause the workpiece to substantially conform to a mandrel (punch, die or stamp). The term "forming" includes "forging" as a subset. Forging involves deforming a relatively thick (compared to stamping) metal workpiece into a desired shape by applying force or pressure, and usually heat. As used in this document, the term "surface" denotes the surface region of a material. Thus, friction stir processing of a surface involves processing material to a predetermined distance below the actual surface. The FSP tool is the rotating bit that moves through the workpiece material during friction stir processing.

The present invention provides an improved golf club and a method for improving the performance of a golf club via friction stir processing to enhance the hardness of at least a portion of the surface of the golf club face. The face is the part of the club that contacts the golf ball during operation. Enhanced face hardness tends to increase the momentum transfer efficiency between the club and the ball so as to provide increased loft, increased distance, and better control over the final location of the ball. Friction stir processing also tends to remove voids and defects in the metal that might otherwise decrease momentum transfer efficiency. Since the friction stir processed surface layer is an integral part of the golf club face, energy losses that would result from the interface between an insert and the club head are eliminated.

The friction stir processed face is also more resistant to wear, which tends to improve

golfing consistency and extend the lifetime of the club. Increased wear resistance should be particularly advantageous for the outer edges of grooves in the club face designed to enhance ball backspin. Wear of such edges is especially rapid and has a substantial effect on performance. The FSP treatment is inexpensive to apply, enabling high quality golf clubs to be fabricated at reduced costs.

Friction stir processing according to the present invention is preferably limited to a thin (1 – 3 mm thick) surface region of the metal so that the properties of the underlying bulk metal are substantially unaffected. In this case, hardness is imparted to the club face surface region without substantially affecting the forgability, mechanical properties, or impact resistance of the supporting material. This provides enhanced flexibility with respect to golf club fabrication and peripheral weighting. For example, the bulk properties of the metal workpiece used to forge a club head can be optimized for the forging operation, and performance characteristics, such as good impact resistance, while still gaining the face hardness needed for high performance. Within the scope of the present invention, thicker or thinner friction stir processed regions may also be used.

Friction stir processing according to the present invention may be performed either before or after the golf club head is formed. In a preferred embodiment, the metallic golf club head is first formed by casting or forging, for example, and friction stir processing is then performed over at least a portion of the surface of the club face. Since the friction stir processed surface is typically uneven and to some extent rough, it is generally necessary to re-surface the friction stir processed area, preferably by milling. As part of the re-surfacing process, desirable features (grooves, for example) may be produced (or restored) in the club face. In another embodiment, friction stir processing is first performed on at least a portion of a surface of a metallic workpiece (strip, plate or block of metal, for example), which is then formed, preferably by forging, into a golf club head having at least a portion of the friction stir processed area within the club face. In this case, the friction stir processed area is preferably re-surfaced before the forming operation but re-surfacing could be performed after formation of the club head. The invention further provides a golf club, and a method of fabrication, that provides feedback with respect to the performance of the golfer. For this embodiment, the "sweet spot" on the face of a practice club, within which the ball is propelled through the optimum trajectory, is friction stir processed whereas the remainder of the club face is not subjected to friction stir processing. A proficient

golfer will feel that the ball is impacted more solidly by the FSP hardened sweet spot, compared to the softer surrounding material. This difference in feel when the ball is impacted within the FSP defined sweet spot provides immediate feedback for improving the golfer's swing. The size of the FSP processed sweet spot for the practice club may be matched to the proficiency of the golfer, being smaller for a more proficient golfer. In addition, since wear is substantially reduced for the FSP hardened sweet spot, the extent of wear observed for the softer surrounding material may be used as a long-term indicator of a golfer's performance. In this embodiment, significant wear outside the sweet spot defined by the FSP surface treatment would indicate that the ball was frequently struck outside the sweet spot, where the material is softer. The softness of the base material, not subjected to the FSP treatment, may be varied to provide faster or slower performance feedback to the golfer.

Any friction stir processing equipment and conditions providing an acceptable fine-grained microstructure may be used to practice the invention. A variety of FSP tool shapes and sizes are available commercially. A typical FSP tool has a spiral-shaped pin and cylindrical shoulder. Features on the pin tend to cause the workpiece material to flow toward the surface during friction stir processing, and have a diameter in the 2 mm to 15 mm range. The pin feature on the FSP tool is not required but may be added for ease of operation. The shoulder is designed to contain and reforge the processed material and has a diameter in the 6 mm to 50 mm range. Typical FSP tool materials are tool steels, polycrystalline cubic boron nitride, nickel-based super alloys, tungsten carbide, and other tungsten-based alloys. FSP tools typically rotate at 150 to 2000 rpm and move along the surface of the workpiece at 50 to 7000 mm/minute. Friction stir processing equipment is available commercially from MTS, General Tool, and ESAB. As those skilled in the art will appreciate, a variety of tool designs could be used to achieve the same increased hardness results.

Larger areas are typically friction stir processed by rastering, which involves multiple parallel passes of the FSP tool along the workpiece surface. Raster passes are typically overlapped but this may not be necessary. As those skilled in the art will appreciate, the tool could be moved in various other patterns, circular spirals, for example, to friction stir process larger areas.

Description of a Preferred Embodiment

The faces of two number 6 irons with 431 stainless steel heads were friction stir processed to a depth of 1.6 mm using a polycrystalline cubic boron nitride tool with a 12.7 mm shoulder diameter. The tool was rotated at 900 rpm and was passed, with a tilt angle of 3 degrees, along the centerline of the club face at a rate of 50 mm/minute. It is estimated that the surface temperature approached 1100°C. The workpiece was actively cooled by water quenching during the FSP operation to freeze in the hardened microstructure. Two passes with 50% overlap were made for each club face to provide a larger sweet spot for hitting the ball. Such rastering could be avoided by using a larger diameter tool. After the FSP treatment, the club faces were machined by milling to remove surface roughness and uneveness, and to fabricate grooves needed for ball spin control and water removal.

Example 1—One of the friction stir processed club heads was cross-section for microscopic examination and hardness testing. Figure 1 shows an optical micrograph of the cross-section, which illustrates the fine-grained microstructure produced in the surface region by the FSP treatment. Figure 2 shows the Rockwell "C" hardness values measured at various distances from the surface (hardness indents shown in Fig. 1) using a Knoop hardness tester with a 500 g load. The FSP treatment increased the hardness from about 26 for the bulk material to more than 40 at the face surface.

Example 2—The intact friction stir processed (FSP) six iron was compared to a stock (unprocessed) six iron of the same type by an objective evaluator, who is a professional golf club fitter and expert golfer. This evaluator reported that balls hit with the FSP iron tended to attain higher loft and somewhat greater distance compared to those hit with the stock six iron. The evaluator also reported that the FSP six iron hit balls with a more solid feel.